

## *Ab initio* No Core Shell Model Study for Lighter Nuclei

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### Introduction

Due to recent progress in the computational facilities, now it is possible to study medium mass (lower *sd* shell) nuclei using *ab initio* no core shell model (NCSM) approach. For the upper *sd* shell nuclei there is another method where the effective interactions from *ab initio* approaches are projected for a particular model space and these interactions are used in the shell model calculations. The aim of the present thesis [1] is to perform *ab initio* no core shell model (NCSM) calculations for lighter nuclei and to perform shell model calculations using valence-space Hamiltonians derived with *ab initio* approaches like in-medium similarity renormalization group (IM-SRG) and coupled-cluster effective interaction (CCEI) for heavier *sd* shell nuclei.

### Overview of present thesis work

A systematic study of low-lying energy spectrum for  $^{18-23}\text{O}$  and  $^{18-24}\text{F}$  isotopes using NCSM is presented [2]. In NCSM, the Hamiltonian used in the calculations is an effective Hamiltonian in model space  $P$  and cut off by model space size parameter  $N_{max}$ . The Hamiltonian is dependent on variational parameter harmonic oscillator (HO) frequency  $\hbar\Omega$  and parameter  $N_{max}$ . For the diagonalization of the matrices, we have used pANTOINE code. For diagonalization, it uses Lanczos method to find eigenvalues and eigenvectors of a sparse and huge, Hermitian matrix. This code can handle the dimensions up to  $\sim 10^{10}$  in  $m$ -scheme.

We have used inside nonlocal outside Yukawa (INOY) potential, which is a two body interaction but also have the effect of

three body forces by short range and nonlocal character. We have also performed calculations with next-to-next-to-next-leading order (N3LO), and next-to-next leading order (N2LOopt) interactions and corresponding results are compared with the experimental data and phenomenological interaction USDB. The INOY and N3LO are the effective interactions while N2LOopt is a bare interaction.

The largest model space we have reached for  $^{18-21}\text{O}$  and  $^{18-19}\text{F}$  is  $N_{max}=6$  and for other oxygen and fluorine isotopes is  $N_{max}=4$ . The over binding in g.s. energy in neutron rich oxygen isotopes is observed in our largest model space calculations. The results with INOY interaction show good agreement with the experimental data. The most important finding of the present study is the location of drip-line in oxygen isotopes even using only two body interaction.

The neutron rich  $^{18-22}\text{N}$  isotopes have been studied using NCSM method [3]. To calculate the energy spectrum we have used three different  $NN$  potentials: INOY, N3LO from chiral effective field theory and charge-dependent Bonn 2000 (CDB2K). The calculations have been done at  $\hbar\Omega=20$  MeV, 14 MeV and 12 MeV using INOY, N3LO and CDB2K potentials, respectively. Apart from this, we have also performed shell model calculations with the YSOX interaction which includes (0-3)  $\hbar\Omega$  excitations in full  $p-sd$  model space. The results with INOY interaction show good agreement with the experimental data in comparison to the other three interactions. The INOY interaction ( $\hbar\Omega=20$  MeV) gives correct g.s. for all  $^{18-22}\text{N}$  isotopes. We also show the g.s. energy of  $^{18-22}\text{N}$  isotopes corresponding to  $N_{max}=4$  model space size with INOY interaction at  $\hbar\Omega=20$  MeV. The g.s. energy follows the same trend as the experimental data.

The electromagnetic properties of *sd* shell have been investigated using valence-space

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Hamiltonians derived with two *ab initio* approaches [4]: IM-SRG and CCEI. These effective interactions are based on chiral effective field theory, where  $NN$  and  $3N$  parts are taken from a N3LO chiral nucleon-nucleon and a N2LO chiral three-body interaction, respectively. The  $\hbar\Omega$  values for IM-SRG and CCEI effective interactions are 24 MeV and 20 MeV, respectively. For both IM-SRG and CCEI, we use  $\Lambda_{NN} = 500$  MeV for the chiral N3LO  $NN$  interaction, and  $\Lambda_{3N} = 400$  MeV for the chiral N2LO  $3N$  interaction. The magnetic dipole moments and electric quadrupole moments values are calculated with  $e_p = 1.5e$ ,  $e_n = 0.5e$ , and  $g_s^{eff} = g_s^{free}$ . The results are in a reasonable agreement with the available experimental data as well as with the results from the phenomenological USDB effective interaction. Using these *ab initio* interactions the  $B(E2; 2_1^+ \rightarrow 0_1^+)$  transitions for Ne, Mg and Si isotopes have been also discussed [5]. This work will add more information to the available *ab initio* results for the spectroscopy of *sd* shell nuclei.

A systematic shell model study has been done using *ab initio* effective interactions for Gamow-Teller transition strength distribution of *sd* shell nuclei [6]. The *ab initio* effective interactions are based on IM-SRG and CCEI approaches. The aim of the present work is to test the predictive power of *ab initio* effective interactions for available experimental data of Gamow-Teller strength distributions for 13 sets of transitions of *sd* shell nuclei. The results are also compared with the phenomenological USDB and experimental data. The *ab initio* results of the Gamow-Teller ( $GT_+/GT_-$ ) strength distributions reproduce the experimental data with reasonable agreement. We have also calculated the electron capture reaction rates for  $^{23}\text{Na}(e^-, \nu)^{23}\text{Ne}$  and  $^{25}\text{Mg}(e^-, \nu)^{25}\text{Na}$ . The GT calculated strengths are found to be applicable to evaluate nuclear weak rates for some lower-mass *sd* shell nuclei, such as  $^{23}\text{Na}$  and  $^{25}\text{Mg}$ , within a factor of 2-4 in stellar environments. These nuclear weak rates play important roles in astrophysical processes.

The structure of  $^{35,37,39}\text{S}$  isotopes [7] is described by performing comprehensive

shell model calculations with SDPF-U and SDPFMW interactions. Protons and neutrons are restricted to the *sd*-shell for  $N < 20$ , neutrons start to fill the *pf*-shell for  $N > 20$ . The natural parity states are described by only in-shell mixing and unnatural parity states with 1p-1h inter-shell neutron excitations. With SDPF-U interaction, reported are the results for natural parity states only because this interaction is not suitable for cross shell excitations. Overall the SDPFMW interaction is seen to be much better for describing simultaneously properties of levels of both parities in  $^{37,39}\text{S}$  isotopes. We have also calculated the electric quadrupole and the magnetic dipole moments for  $^{35,37,39}\text{S}$  and spectroscopic factors in  $^{37}\text{S}$ . The shell model results are in good agreement with recently available experimental data.

## Acknowledgments

I would like to thank my Ph.D. supervisor, Dr. Praveen C. Srivastava for his comments, suggestions and guidance during my thesis work. I acknowledge MHRD Govt. of India for providing financial support during Ph.D. thesis work. I would like to thank P. Navrátil and C. Forssén for several useful discussions during this work and also acknowledge Oak cluster at TRIUMF.

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